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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

Test Operations Procedure (TOP) 1-2-618 3 November 2008
DTIC AD No.

INITIAL NUCLEAR RADIATION HARDNESS VALIDATION TEST

*This TOP supersedes TOP1-2-618, dated 31 July 1996.

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1. SCOPE.

This Test Operations Procedure (TOP) is an outline of the test and evaluation procedures required to assess the effects of the Initial Nuclear Radiation (INR) environments on Army materiel. The INR environments are comprised of the Gamma Dose Rate (GDR), Gamma Total Dose (GTD) and Neutron Fluence (NF) environments. The purpose of this test and evaluation procedure is to ascertain the degree to which the Mission Need Statement (MNS), Operational Requirements Document (ORD), Capabilities Performance Document (CPD) and the Army Nuclear Hardening Criteria (NHC) are met. Army materiel can consist of a variety of configurations, such as complete end items, subsystems, Line Replaceable Units (LRUs), or electronic microcircuits. All materiel must be tested and evaluated to its NHC with respect to all mission essential functions. Realistic and practical test configurations and scenarios must be contemplated in order to achieve an accurate and complete Nuclear Survivability Test and Assessment (NTSA). All NTSAs must include a three phase approach in order to meet the requirements of Department of Defense Instruction (DODI) 5000.2[1**], AR70-75[2] and its NHC[3]. The three phases are

a. The electronic microcircuit test phase

b. The system analysis phase

c. The system level test phase.

The combination of these three phases will result in an overall micro-to-macro system INR survivability determination and assessment. Factors that affect the scope and execution of the NTSA program phases are schedule, cost, technology and mission. This TOP adheres to an integrated set of test principles and procedures which will result in a timely, reliable, and consistent analysis and assessment of the system level test phase. The scope of this TOP does not include an in depth education in the theory of creation or measurement of the nuclear environments.

2. FACILITIES AND INSTRUMENTATION.

2.1 Gamma Dose Rate Facilities and Instrumentation.

2.1.1 Gamma Dose Rate Criteria Parameters.

These criteria parameters must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

Prompt gamma radiation pulses generate the production of charge carriers and subsequent photocurrents. These damaging photocurrents which flow across device junctions induce transient upset, latch-up and/or burnout in the semiconductor devices.

Gamma Dose Rate Parameter	Units
Peak Gamma Dose Rate	[cGy(Si)/sec]
Pulse Width	[nanoseconds]
Energy	[Mev]

[**] Superscript numbers correspond with those in Appendix G, References.

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, acceptable damage and degradation, and the availability of and time required to implement repair and replacement parts.

2.1.2 Gamma Dose Rate Facilities.

Acceptable test facilities can be categorized as electron Linear Accelerators (LINAC), or flash X-Ray simulators. Major military systems and subsystems should utilize flash X-ray simulators because they can irradiate large test systems, while LINACs should be utilized on electronic piece-parts, components, and circuit card assemblies because of cost effectiveness, pulse-width variability, and quick turn-around times. Examples of acceptable facilities are:

Facility	Type	Location	Comments
1. USA WSMR LINAC	LINAC	WSMR, NM	Max Dose Rate - 2E11 cGy(Si)/sec Pulse Width - 10 ns to 10 s Piece part and component level
2. USA WSMR REBA	Flash X-ray	WSMR, NM	Max Dose Rate - 2.6E11 cGy(Si)/sec Pulse Width - 50 to 85 ns Up to system level
3. DOE SNL HERMES III	Flash X-ray	Kirtland Air Force Base (KAFB), NM	Max Dose Rate - > 5E12 cGy(Si)/sec Pulse Width - 20 ns Large system level

Other GDR facilities are listed in "A Complete Guide to Nuclear Weapons Effects (NWE) Simulator Facilities and Applications", (2001 Edition). It must be noted that this edition was the last published NWE Simulator Facilities and many of these facilities are not currently operational. The Test Officer (TO) must ensure that the GDR test facility utilized is the foremost facility to accurately simulate desired criteria over an adequate exposure area and test item responses in order to adequately test the system configuration. It is emphasized that available facilities will provide only a simulated GDR environment. Therefore, in addition to good test data, adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.1.3 Gamma Dose Rate Instrumentation / Dosimetry.

Measurement Parameter	Preferred Device	Measurement Accuracy
Photocurrent	Photocurrent Probes	±5%
Gamma Dose	**CaF_2 (Mn) TLD	±10%
Gamma Radiation Pulse	PIN Diode Compton Diode	±10% ±10%
Current	Multimeter/Digitizer Oscilloscope	±10%
Voltage	Multimeter/Digitizer Oscilloscope	±5%

**Other materials may be utilized instead of Calcium Fluoride (Manganese) (CaF_2 (Mn)) to determine gamma dose. However, the material's calibration and detection must conform to the procedures outlined in "Annual Book of American Society for Testing and Materials (ASTM) Standards[3]", Section 12.

The gamma dose is generally measured using CaF_2 (Mn) Thermo Luminescent Dosimeters (TLDs). The measured gamma dose values will be expressed in cGy(Si) and cGy(tissue) by these general ratios, but the "Annual Book of ASTM Standards[4]", E666 and E668 must be referenced for each test:

$$cGy(Si)/cGy(CaF_2) = 1.02 \text{ and } cGy(tissue)/cGy(CaF_2) = 1.13, \text{ respectively.}$$

Each radiation pulse will be measured using a PIN or Compton diode and digitized on a transient digitizing system. The pulse-width (Full Width Half Maximum (FWHM)) of each radiation pulse will be obtained from this digitized signal. The GDR for each pulse will then be determined from the dose recorded on the TLDs and divided by the pulse-width obtained from the digitizers.

2.2 Neutron Fluence Facilities and Instrumentation.

2.2.1 Neutron Fluence Criteria Parameter.

This criteria parameter must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

Fast neutrons interact with semiconductor material in electronic piece-parts by elastic collisions with lattice atoms which decrease minority carrier lifetimes and increase device resistivity. This resulting damage alters electrical parameters of the device which can cause failure in the semiconductor devices or circuit applications.

Neutron Fluence Parameter	Units
Neutron Fluence	[1 Mev(Si) n/cm^2]

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, acceptable damage and degradation, and the availability of and time required to implement repair and replacement parts.

2.2.2 Neutron Fluence Facilities.

Acceptable test facilities can be categorized as a Fast Burst Reactor (FBR) or a Training, Research, Isotopes, General Atomics (TRIGA) reactor. (Sometimes, Californium-252 is utilized for piece-part testing.) These reactors generally can be utilized in the pulse or steady-state mode of operation. In the pulse mode of operation, the FBR can generate neutron fluence up to 5E14 n/cm^2 with energies > 10 keV and GDR up to 1E9 cGy(Si)/sec with a pulse-width of approximately 50 micro-seconds (µsec). However, when total neutron fluence is the primary concern, the steady-state mode of operation is typically used. Examples of acceptable facilities are:

Facility	Type	Location	Comments
1. USA WSMR Fast Burst Reactor	FBR	WSMR, NM	Peak Pulse Power - 6.5E4 MW Neutron Fluence - 7E13 n/cm^2 FWHM Pulse Width - 40 to 3000 s Up to system level

Other neutron fluence facilities are listed in "A Complete Guide to Nuclear Weapons Effects Simulator Facilities and Applications", (2001 Edition). It must be noted that this edition was the last published NWE Simulator Facilities and essentially all of these facilities are not currently operational. The TO must ensure that the neutron fluence test facility utilized is the foremost facility to accurately simulate desired criteria and test item responses in order to adequately test the system configuration. It is emphasized that available facilities will provide only a simulated neutron fluence environment. Therefore, in addition to good test data, adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.2.3 Neutron Fluence Instrumentation / Dosimetry.

Measurement Parameter	Preferred Device	Measurement Accuracy
Neutron Fluence	** Sulfur Activation Foil	±10%
Gamma Dose	**CaF_2 (Mn) TLD	±10%
Current	Multimeter/Digitizer Oscilloscope	±5%
Voltage	Multimeter/Digitizer Oscilloscope	±5%

**Other materials or techniques may be utilized instead of sulfur and CaF_2 (Mn) to determine neutron fluence and gamma dose, respectively. However, the material's calibration and detection must conform to the procedures outlined in "Annual Book of ASTM Standards", Section 12.

The neutron fluence at each test location will be measured using sulfur activation foils which measure neutrons with energies greater that 3 MeV; but, the "Annual Book of ASTM Standards[3]", E720, E721, and E722 (specifically E722-93) must be referenced. The measured fluence will be converted to 1 MeV(Si) equivalent damage fluence by the following relationship:

1 MeV(Si) eq. neutron fluence = K * (3 MeV neutron fluence)

where K is experimentally determined with respect to many factors, such as energy, spectrum, and source-to-target distance.

The gamma dose will be measured using CaF_2 (Mn) TLDs. The measured gamma dose values will be expressed in cGy(Si) and cGy(tissue) by these typical ratios, but the "Annual Book of ASTM Standards", E666 and E668 must be referenced for each test:

$$cGy(Si)/cGy(CaF_2) = 1.02 \text{ and } cGy(tissue)/cGy(CaF_2) = 1.13, \text{ respectively.}$$

2.3 Gamma Total Dose Facilities and Instrumentation.

2.3.1 Gamma Total Dose Criteria Parameter.

This criteria parameter must be thoroughly analyzed to ensure that acceptable facilities and appropriate instrumentation are utilized.

Gamma Total Dose (GTD) generates hole-electron pairs through the process of ionization in the semiconductor material resulting in trapped charges. These total dose effects are exhibited either as a change in electrical parameters or as a catastrophic failure in semiconductor devices.

Gamma Total Dose Parameter	Units
Gamma Total Dose	[cGy(Si)]

Obtaining the proper total gamma dose test criterion can be difficult. The TO must first obtain NHC and identify the subheading: "Silicon Absorption / Displacement Damage". Under this subheading, is the title " Max Combined Neutron and Gamma Ionizing Dose, (cGy(Si))" referred to as D_i. In addition, the correct utilized value should have in quotes (single pulse duration of 60 seconds). This acquired value is the actual Center-Of-Mass (COM) GTD to be received by the test item.

Performance criteria requirements of the test system include allowable downtime and recovery procedures, operate through, recovery time, degradation and/or acceptable damage, and the availability of and time required to implement repair and replacement parts.

2.3.2 Gamma Total Dose Facilities.

Acceptable test facilities typically utilize a Cobalt-60 source or multiple Cobalt-60 sources. Large systems are extremely difficult to test adequately because no large scale DOD /DOE gamma dose facility is available. Therefore, most testing should be accomplished at the piece-part, component, LRU, and subsystem level. Whole body irradiations are typically limited to surfaces < 1.5 m on a side for gradient and disposition rate reasons. Examples of acceptable facilities are:

Facility	Location	Comments
1. USA WSMR GRF	WSMR, NM	Max Dose Rate - 1700 cGy(Si)/sec Exposure Area - 13 x 6 x 4 height m 8 sources Piece-part, Component, LRU, subsystem and system level
2. SNL Gamma Facility	KAFB, NM	Max Dose Rate - 600 cGy(Si)/sec Exposure Area - 15.2 cm dia. x 20.3 height cm Piece-part, Component, small LRU/subsystem level

Other gamma total dose facilities are listed in "A Complete Guide to Nuclear Weapons Effects Simulator Facilities and Applications", (2001 Edition). It must be noted that this edition was the last published NWE Simulator Facilities and many of these facilities are not currently operational. The TO must ensure that the GTD test facility utilized is the foremost facility to accurately simulate desired criteria over an adequate exposure area and test item responses in order to adequately test the system configuration. It is emphasized that available facilities will provide only a simulated gamma total dose environment. Therefore, in addition to good test data, adequate analysis must be performed to account for the facility deficiencies which must be known, quantified, and documented.

2.3.3 Gamma Total Dose Instrumentation / Dosimetry.

Measurement Parameter	Preferred Device	Measurement Accuracy
Gamma Dose	**CaF_2 (Mn) TLDs	±10%
Current	Multimeter/Digitizer Oscilloscope	±5%
Voltage	Multimeter/Digitizer Oscilloscope	±5%

** Other materials may be utilized instead of CaF_2 (Mn) to determine gamma dose. However, the material's calibration and detection must conform to the procedures outlined in "Annual Book of ASTM Standards, Section 12".

The gamma dose will be measured using CaF_2 (Mn) TLDs. The measured gamma dose values will be expressed in cGy(Si) and cGy(tissue) by these typical ratios for Cobalt 60, but the "Annual Book of ASTM Standards[3]", E666 and E668 must be referenced for each test:

$$cGy(Si)/cGy(CaF_2) = 1.02 \text{ and } cGy(tissue)/cGy(CaF_2) = 1.13, \text{ respectively.}$$

3. REQUIRED TEST CONDITIONS.

3.1 Test Preparation.

Test preparation should be performed in accordance with TOP 1-2-612[4] Section 3.1. As indicated above, this TOP describes the methods of performing a system level INR test and analysis. It cannot be overemphasized that a complete NTSA program also requires electronic microcircuit test and analysis, and a system circuit analysis phase. All three phases are critical in providing the entire micro-to-macro model analysis of a system.

3.2 Test Chronology.

All effects produced by a nuclear weapon are dependent upon weapon yield, weapon type, type of burst, height of burst (HOB), and distance. Figure 1 presents the time history of environments produced by a 27 kilo-TON fission weapon detonated at a HOB of 180 m at a distance of 1 km (Please note that Figure 1 is a chronological representation of the environments only and is not intended as a reference; should further references be required refer to APPENDIX C). As is indicated in this figure (y-axis values are normalized per environment and do not represent any relationship in magnitudes), the first environment to arrive at the location of interest is the gamma environment (this is presented as the Gamma Dose Rate (GDR) and Prompt Gamma Total Dose (PGTD). This is followed by a continuing Gamma Total Dose (GTD) environment (at a much lower deposition rate through 1 minute) and then a short time later by the Neutron Fluence (NF) environment.

This environment delivery scheme provides a simple test chronology. The GDR is always tested as the first environment of the NTSA followed by the GTD and finally the neutron environments. As can be seen in the figure, approximately 50% of the GTD is provided prior to and 50% of the GTD is provided after the arrival of the neutrons. The physics of damage in common electronic microcircuits to the GTD and NF environments is such that the environments can be performed in either order. Based upon the experimental design, these environments can be alternated to maximize the test hardware allocation. However, the physics of damage in common electronic microcircuits when exposed to the GDR environment is such that this test can never follow the NF environment. This is due to the fact that most microcircuit damage is incurred as a result of GDR induced latch-up and preceding burnout. This latch-up is characterized by the microcircuit entering a non-functional state and consuming excessive power supply and/or input currents. These excessive currents can damage the microcircuit through thermal breakdown of the semiconductor material or device metallization. The latch-up path is part of the microcircuit physical layout and is the unintentional creation of parasitic secondary four-layer devices which resemble Silicon Controlled Rectifiers (SCRs). The functioning of these secondary SCRs can be greatly influenced by the neutron environment that will degrade the overall gain of the parasitic SCR (high levels of NF exposure have been used as a means of hardening certain types of microcircuits by eliminating the GDR induced latch-up mechanism in susceptible microcircuits). Therefore, the NF environment can never be performed, prior to the GDR environment to adequately simulate INR effects.

3.3 Determination of Effects.

The determination of effects of each of the tests outlined in this TOP are based on measures taken after the tests which indicate damage incurred by the item as a result of a particular INR test environment. In order to fully characterize any potential damage, the post-test measures must be reviewed in light of the baseline pre-test measures (i.e. delta change and the impact on the equipment or circuit on the mission). These measures may be unique to the type of item being tested and several measures may be utilized to clearly define the functionality. These measures should reflect both the functionality and overall performance of the test item (piece-part, circuit, LRU and system), whenever possible. Whenever possible, Circuit Card Assemblies (CCAs), sub-system, LRU and system self-check processes are utilized to adequately quantify the impact, since these

processes are the most efficient and reasonable to identify the actual performance. However, priority should be given to identification of a performance-related measure which could be tested after each irradiation relative to the baseline performance. To summarize, experimental design, test coordination and test planning are critical activities to determining and quantifying the INR survivability of any test item.

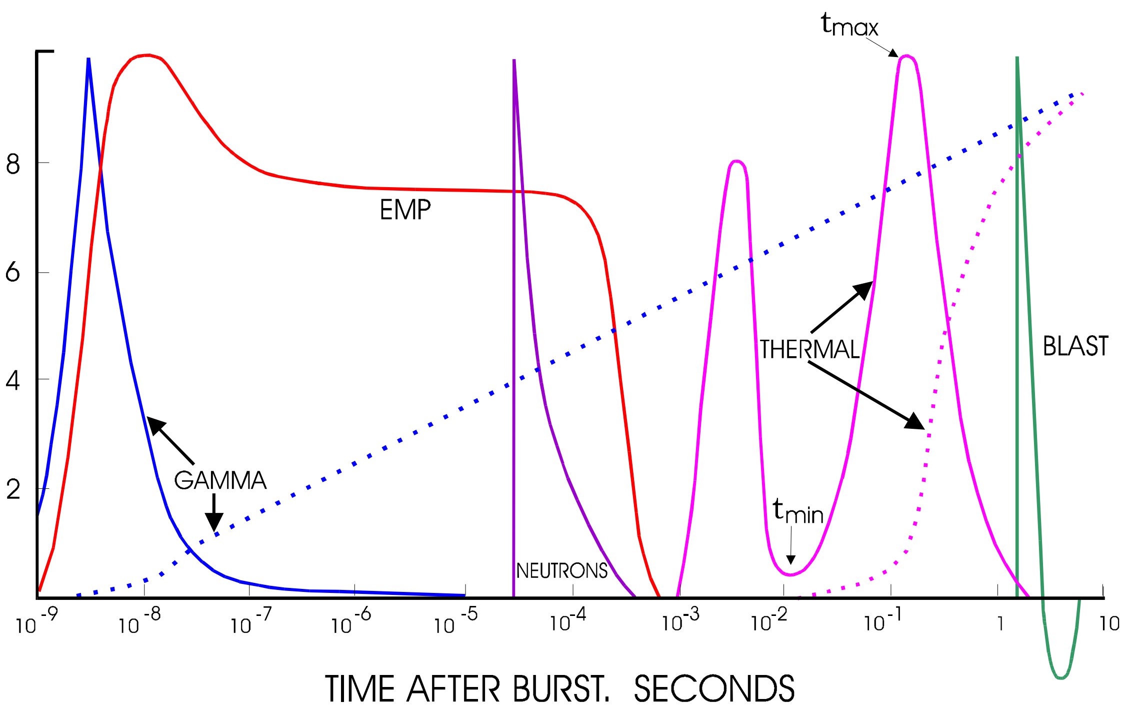

Figure 1: Example Time History From 27 kT Nuclear Weapon.

3.3 General Radiation Effects.

As a prerequisite a familiarity with TOP 1-2-612 is strongly recommended. The unique issues / concerns of each INR environment will be addressed separately below:

3.3.1 Gamma Dose Rate.

3.3.1.1 GDR Environment Induced Effects.

The primary effect of the GDR environment is ionization and transient damage of the material that the environment is applied upon. In the case of electronics, this material is some form of semiconductor material, predominantly silicon. The ionization produces the generation of gamma photon induced transient currents called photocurrents. These photocurrents produce secondary effects that include:

a. Error generation in logic and analog circuits.

b. Secondary photocurrents.

c. Photocurrent induced burnout.

d. Latch-up.

e. Memory Device Corruption.

f. Electronic Microcircuit Damage.

As can be seen from this variety of effects, the GDR induced response can be as small as an unnoticed error, or as catastrophic as a completely inoperable system.

3.3.1.2 General Protection Methodology.

As indicated above, the primary response to the GDR environment is the production of photocurrents. In silicon, the hole/electron pair produced by 1 cGy(Si) is approximately $4.2X10^{13}$ pairs/cm^3. It is apparent from this pair production rate that the GDR environment is capable of producing large photocurrents, particularly when tens or hundreds of cGy(Si) are involved. The photocurrents generated are limited by the size of the microcircuit active area, the magnitude, pulse-width and energy of the GDR environment, and the ability of the electronic circuit design to provide paths for these induced currents. Intuitively, the solutions for the reduction in photocurrents are the reduction in:

a. The Microcircuit's Active Area.

b. The GDR environment.

c. The Applicable Circuit's Current Capacity.

In order to accomplish the reduction in the Microcircuit's Active Area, this is accomplished in today's' technology by the use of specially made integrated circuits which use insulator materials as substrates, such as Silicon-On-Sapphire (SOS) or Silicon-On-Insulator (SOI). The second reduction technique in the GDR environment can be accomplished by the addition of high density material such as lead and is called shielding. However, utilizing this mitigation to the GDR environment by shielding is not effective or practical, due to the impact on the system's weight, space claim and performance degradations. The last reduction in Applicable Circuit's Current Capacity is accomplished utilizing one or more of the following four methods:

a. Resistive Current Limiting.

b. Inductive Current Limiting.

c. NF Irradiation.

d. Power Removal (crowbarring (manual) and circumvention (automatic))
(Recommend < 250 µsec to first time constant)

Each of these four methods, provide different circuit implementation that must be adequately considered, prior to the selection of the mitigation / protection technique. Normally, the primary method utilized in systems that do not have an "Operate Through" requirement is the GDR induced power removal technique. The proper integration / implementation of the proper power removal methodology throughout a system are perhaps the most critical and cost effective of all INR survivability tasks. It must be noted that this integration must be implemented ASAP in a system design. For device / piece-part comparison GDR threshold values see Table E-1 starting on page E-2.

3.3.2 Gamma Total Dose.

The GTD environment includes the effects of both the gamma and X-ray spectrums, with the gamma photons being produced when an excited electron falls to its normal valence shell and emits a photon of energy. This photon is similar to electromagnetic waves which are produced at atomic dimension frequencies. The X-rays are produced as an electron passes near an atom and is changed in direction. This change in direction causes the electron to radiate significant energy. The radiated energy is called Bremsstrahlung or braking radiation and consists of high energy X-ray photons. For ground-based or near-surface systems, X-rays are not of direct concern because they are absorbed within a few meters of the detonation. However, these X-rays are critical to high-altitude or space-based systems.

3.3.2.1 GTD Environment Induced Effects.

The GTD environment is significant in electronic microcircuits which contain highly resistive isolation techniques such as the Metal Oxide Semiconductor (MOS) devices. The GTD environment produces hole-electron pairs that have sufficient energy to be separated by the highly resistive isolation and not allowed to recombine (trapped), resulting in a net microcircuit charge. This residual charge results in a shift in the activation and deactivation threshold levels for the microcircuit. If the shift is significant, the microcircuit will no longer respond as required WRT to its datasheet specification. Additionally, this residual charge can also result in the change in logic of a memory storage device, resulting in false instructions being generated and is normally manifested as once a "1" is written, location remains a "1" even after a "0" instruction.

3.3.2.2 General Protection Methodology.

There are no general overall hardening GTD procedures to follow (as there were for the GDR environment) that will reduce the effects of the GTD environment. Based upon experience and historical test data, it has been observed in many microcircuits that the exposure of the electronics while in an unpowered / unbiased state will considerably improve their GTD survivability threshold. This implies that very fast responding GDR induced power removal is one method for improving microcircuit GTD survivability. However, the primary method of improving GTD susceptibility is through the use of technology and piece-part selection processes. For device / piece-part comparison GTD threshold values see Table F-1 starting on page F-2. The avoidance of NMOS microcircuits is highly recommended since their response has proven to be the worst of all technologies. This is

normally not difficult, since pure NMOS devices are rare in the current technology, which is predominantly CMOS technology. As with all testing, the GTD survivability of a LRU or circuit is determined at its weakest building block, which is normally at the device and circuit level. It is critical to the qualification testing that power removal is taken into account when determining its survivability. As shown in Figure 2, CCAs and LRUs must account for unbiased exposure based upon a reasonable power removal time. As an example, if a LRU can remove power to its first time constant within 400 μsecs, the LRU is exposed in a biased condition 50% of the GTD exposure time.

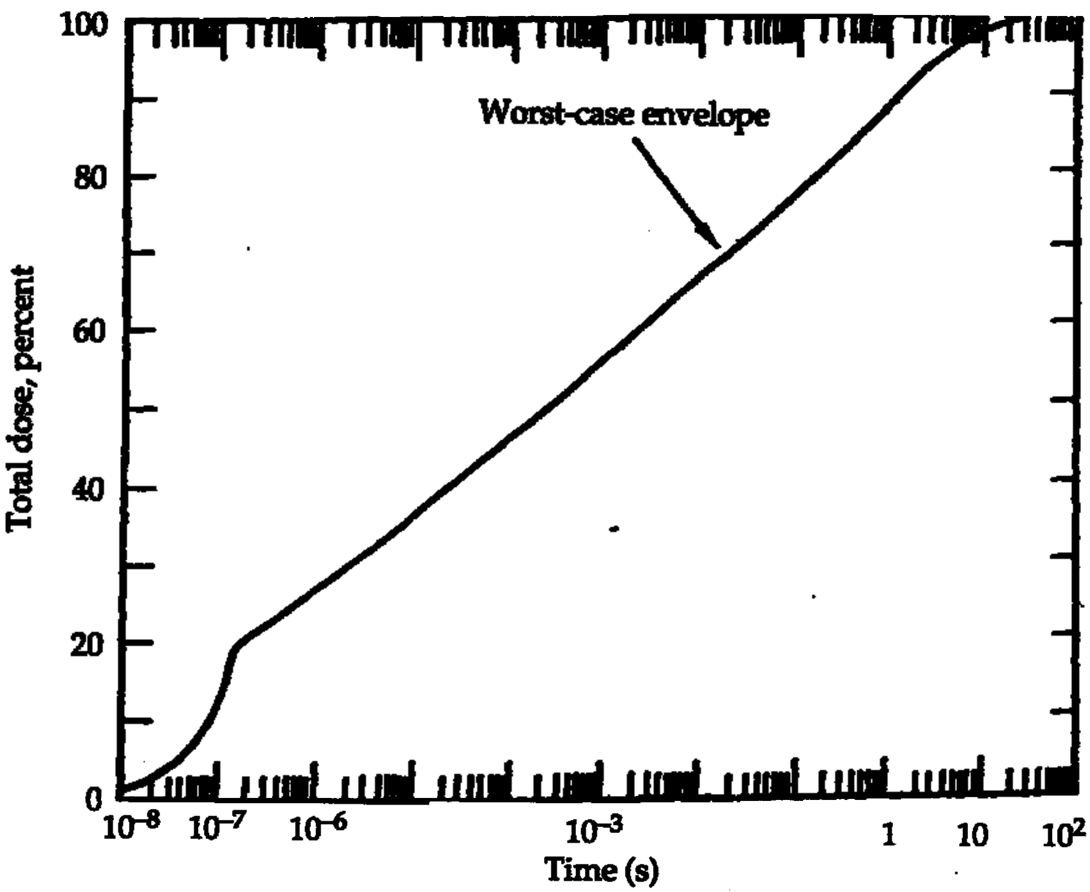

Figure 2: GTD Percentage Applied Based Upon Power Removal.

3.3.3 <u>Neutron Fluence</u>.

3.3.3.1 <u>NF Environmental Induced Effects</u>.

The primary effect of the NF environment is the resulting crystal lattice damage of the semiconductor material which it is imposed upon. Neutrons can also produce ionization as a secondary effect to the crystal lattice displacement and transient responses. These transient responses are however, short lived and annealing occurs within minutes and is not considered critical to most Army tactical systems. It must be noted that these transient and displacement effects could become more critical as CMOS technology becomes steadier and smaller than sub-micron. This effect has been observed in highly integrated CMOS devices, such as Synchronous Dynamic Random Access

Memories (SDRAMs). The lattice displacement is evidenced in the reduction of microcircuit parameters. These microcircuit parameters are primary influenced by the reduction in minority carrier life time which directly influences the gain of bipolar devices. This reduction in gain affects other circuit parameters such as output current, input current, and operation.

3.3.3.2 General Protection Methodology.

There are no general overall hardening procedures to follow (as there were for the GDR environment) which will reduce the effects of the NF environment. Since the neutron-induced degradation is primarily the result of crystal lattice damage, there is little or no difference in the degradation effects if the microcircuit is powered or unpowered. The prime method of improving the NF survivability of microcircuits is through the use of technologies which are less susceptible and by utilizing devices with higher operating speeds and less active silicon lattice volume to be disrupted by the neutrons. For device / piece-part comparison NF threshold values see Table G-1 starting on page G-2. A device specification book parameter which can be used in the selection of less susceptible bipolar transistors is the Gain Bandwidth Product (GBP). A generic value of GBP to be used as a cutoff for device selection can be determined by utilizing the Messenger-Spratt transistor degradation equation. The calculation involves determining a maximum generic degradation which is available and then determining the GBP at the required NF. The Messenger-Spratt equation is presented as Equation 1 with the GBP equation being presented as Equation 2.

$$\frac{1}{\beta} = \frac{1}{\beta_o} + \frac{\phi_n}{2\pi x GBP x K}$$

Equation 1: Messenger-Spratt transistor degradation equation

$$GBP = \frac{\phi_n \eta}{2\pi K(1-\eta)}$$

Equation 2: Generic estimate for minimum GBP

where:

K	=	$1.35X10^5$ sec/cm^2 for N type silicon
K	=	2.1X105 sec/cm2 for P type silicon
η	=	% of original gain required
β_o	=	pre-exposure HFE
β	=	post-exposure HFE
GBP	=	Gain Bandwidth Product
Φ_n	=	Neutron fluence
π	=	Pi = 3.14159

The primary method of accounting for NF degradations in microcircuits is to design the electronic circuits so that the overall circuit performance is not degraded. As an example, design the circuits to ensure that the required gain is less than the post neutron value with an acceptable Design Margin

(DM).

4. TEST PROCEDURES.

4.1 Gamma Dose Rate Test Procedures.

4.1.1 General Gamma Dose Rate Procedures.

In this section, the general procedures for performing an adequate GDR test will be discussed. The first requirement is an in-depth familiarity with the system and its normal operation. Without this baseline knowledge, an assessment can not be made. The second requirement is the realization that the GDR environment will be simulated by utilizing some form of electron accelerator. These accelerators are all limited in both size and output and are incapable of producing an adiabatic environment. These simulators all produce a radiation field which is best modeled as a point source with a decrease in magnitude based upon the inverse square law. As such, these simulators are capable of producing the required environment only for narrow isocontours. Therefore, it is necessary to test a test item or system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level, and also ensure that the GDR mitigation circuitry is activated by the exposures. The system should also be exposed to increased levels of GDR to account for the non-adiabatic environment, differences in exposure level due to the inverse square law, dosimetry error, system variability due to microcircuit processing differences, and to allow for an adequate DM. The recommended DM test level is 200% and is utilized to increase the confidence provided by a small sample size (usually one). It must be noted that when an adequate power removal methodology is integrated, the impact of higher DMs should be irrelevant.

4.1.2 Detailed Gamma Dose Rate Procedures.

Presented in TOP 1-2-612, section 5.4, is a set of data required while performing a GDR test. Each of these required data elements will be discussed below:

a. Detailed description of the method of producing the GDR test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

The Test Method should be either electron beam or Bremsstrahlung and source specifications. With current technology, digital photographs are considered the best method of archiving a test setup / procedure. In addition to photographs, the archive and report generation should utilize one of the many computer graphics programs available that can generate clear and concise drawings of the physical test setup. However, with the advent of inexpensive digital cameras, photographs accounting all details of the test setup, performance checkouts and actual induced effects are critical to the documentation process for the TO.

b. Complete set of pretest mapping data in radiation absorbed dose in silicon (cGy(Si)) and absorbed dose in tissue (cGy (tissue)) ±10% for each test location.

This requirement is met by using existing facility data to estimate the Source-To-Target (STT) distances and then refining these STTs by taking pretest GDR irradiations. For each of these characterization irradiations, a series of CaF_2(Mn) TLDs are placed on the centerline axis of the simulator and exposed. These pretest mapping dosimeter readings are then utilized to calculate each required STT distance for a required GDR environment test level. This calculation process must be performed for each electronic item to be exposed. The basic equation is presented as Equation 3 and should be verified against the pretest mapping data. An area equal to the area of the LRU or test item's active electronics must be mapped at each STT. This is required in order to define the exposure level and gradients associated with the test, for each test item, no matter of size or requirements.

$$\frac{\dot{\gamma}_{req}}{D_{target}^2} = \frac{\dot{\gamma}_{map}}{D_{map}^2}$$

Equation 3: Gamma Dose Rate Inverse Square Equation.

where
D_{map} = the distance from the source to the dosimetry point
D_{target} = the distance from the source to the target
$_{map}$ = gamma dose rate at mapping point
$_{req}$gamma dose rate required

Rearranging terms, we have Equation 4 which provides the distance required to achieve a given GDR environment.

$$D_{target} = D_{map}\sqrt{\frac{\dot{\gamma}_{req}}{\dot{\gamma}_{map}}}$$

Equation 4: Target Distance Determination.

c. Information required prior to test execution.

These include test item or system familiarity and descriptions, such as sizes and locations of mission critical electronic equipment and knowledge gained in the testing of other similar military equipment. Of primary importance is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed, and insure that the GDR protection devices (if present) are included and evaluated. In addition it is necessary to ensure that:

(1) Every electronic assemblage will be properly exposed to the GDR environment while in a powered operational state

(2) The function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each GDR exposure,

(3) Each assemblage will have mounted to each surface dosimetry for recording the incident GDR environment and dosimetry for recording the total gamma dose received during the test. The dose rate recording dosimetry must be changed after every exposure. This dosimetry at a minimum should be placed on all vertical surfaces of the LRUs under test, with the largest dimension of the TLD being perpendicular to the incident environment. These dosimeters are used to determine the incident environment on the surface of the LRU and can be used to estimate the internal GDR environment of an LRU.

d. Dosimetry from the GDR environment.

The TLDs should be placed as indicated in the section above and their location used to determine the exposure for each specific LRU. The primary method of recording the gamma environment is through the use of TLDs which measure the total gamma energy received. This total gamma dose measurement is converted to dose rate by Equation 5. The pulse shape of the incident GDR environment is measured using reverse biased diodes. These reverse biased diodes generate photocurrents which are directly proportional to the incident radiation environment (see section 4.1.1). By utilizing very fast recovery diodes such as PIN diodes, the photocurrent response tracks the incident radiation very accurately. The GDR induced current waveforms are then converted to voltage waveforms by a series resistance and this voltage is digitized and stored using digital storage oscilloscopes. From these recorded data, the pulse width of the incident environment may be determined.

$$\dot{\gamma}(CaF_2(Mn)) = \frac{\gamma(CaF_2(Mn))}{P_{width}}$$

Equation 5: Gamma Dose Rate Conversion.

where:

$\gamma(CaF_2(Mn))$ = gamma dose in $CaF_2(Mn)$
P_{width} = full width at half maximum
$(CaF_2(Mn))$ = gamma dose rate in $CaF_2(Mn)$

The $\gamma(CaF_2(Mn))$ is then converted to Tissue and Silicon radiation absorbed dose by Equations 6 and 7, respectively.

$$\dot{\gamma}(tissue) = \dot{\gamma}(CaF_2)X1.108$$

Equation 6: Conversion to cGy(tissue)

$$\dot{\gamma}(Si) = \dot{\gamma}(CaF_2)X1.02$$

Equation 7. Conversion to cGy(Si)

e. System orientation and test data.

The system or test item must be oriented such that all of the active electronics are exposed to the GDR environment while in a powered operational mode. The STT distance must be measured before each exposure to insure that the required levels are received as calculated above. Once all electronics have received the initial test levels (it is best to slowly advance the GDR level to validate test item performance), the test item should be positioned to receive the 200% levels as indicated in para. 4.1.1 above. Any test item which will exceed the 200% level should be shielded from the environment using lead. Shielding may be required during various phases of the GDR test based on the physical geometry and spatial location of the electronics of the test item or system. Again it is emphasized that the primary goal is to expose all the electronics to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to different manufacturing processes, and to account for the small sample size evaluated (usually one). The data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each GDR exposure. Dosimetry from all test item(s), which have a line of sight path to the GDR source should be removed (please note to leave those which are for measuring the test sequence total dose) and evaluated for dose rate achieved.
Utilizing this real time exposure data, the STT distance should be refined using Equations 5 through 7 above until the desired environment has been realized.

4.1.3 <u>Gamma Dose Rate Analytical Procedures</u>.

Section 4.1.2 provides the methods utilized to obtain data during a GDR environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements, the test item(s) that were exposed, the orientation in which they were exposed, and the results of the post exposure checkouts. If any GDR effects are noted, then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The GDR test environment should be scored against the criterion, differences greater than 20% should be addressed and criterion compliance established. These differences should include the reason for the difference and its effect on the system evaluation.

4.1.4 <u>Gamma Dose Rate Follow up</u>.

Follow up to the initial GDR environment should be performed for each susceptible area. One problem that has been noted during many GDR environment tests is the masking of concurrent problems by the destruction of one component. As was discussed earlier, the primary means of electronic circuit failure in a GDR environment is through the activation of a parasitic SCR device latch-up and subsequent burnout. These parasitic SCRs demonstrate all of the common circuit

parameters of the discrete device, in that they have a minimum holding current and voltage. The magnitude of these parameters for a given device is based on the quality of the design flaw. It has been seen that the holding current of latched devices can vary between 30 and 250 mAmps; therefore, an effect called current hogging can play a critical role during a GDR survivability assessment. This current hogging effect is a result of these differences in parasitic parameters, i.e. the device which has the lowest holding current and voltage may allow other latched microcircuits to unlatch, and thereby, protect or mask the other microcircuits. Due to this effect, it is always a requirement to retest a system or test item which has experienced a GDR induced failure / issue to ensure that another failure mechanism was not originally masked (i.e. replacing the old current hogging device may allow a new device to be destroyed).

4.2 Gamma Total Dose Test Procedures.

4.2.1 General Gamma Total Dose Procedures.

In this section, the general procedures for performing a GTD (hereafter referred to as GTD) test will be discussed. The first requirement is an in depth familiarity with the system and its normal operation. Without this baseline knowledge, assessment can not be made. The second requirement is the realization that the gamma dose environment will be simulated by some form of Cobalt 60 source. These sources are all limited in both size and output and are incapable of producing an adiabatic environment. These simulators all produce a radiation field which is best modeled as a point source with a decrease in magnitude based on the inverse square law. Consequently these simulators are capable of producing the required environment only for narrow isocontours. It is therefore necessary to test a system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level and also insure that the gamma dose gradients are kept to a minimum. The system should also be exposed to increased levels to account for: the nonadiabatic environment, deviation in dosimetry, system variability, and allow for a safety margin. It is recommended that 200% of the test level be used to increase the confidence provided by a small sample size (usually one). Ideally the system should be tested one LRU at a time, in order to reduce exposure gradients and to keep the exposure time to less than one minute.

4.2.2 Detailed Gamma Dose Procedures.

Presented in TOP 1-2-612 section 5.6 is a set of data required while performing a GTD. Each of these required data will be discussed below:

a. Detailed description of the method of producing the GTD test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

This requirement is best attained by being familiar with available facilities. If not, then reviewing the facilities listed in the DTRA "A Complete Guide to Nuclear Weapons Effects Simulator Facilities and Applications", (2001 Edition) and requesting a facilities brochure which should contain a description of the radiation producing method (Co_{60} is the preferred source for low dose rate gamma

radiation) and specifications. With current technology, digital photographs are considered the best method of archiving a test setup / procedure. In addition to photographs, the archive and report generation should utilize one of the many computer graphics programs available that can generate clear and concise drawings of the physical test setup. However, with the advent of inexpensive digital cameras, photographs accounting all details of the test setup, performance checkouts and actual induced effects are critical to the documentation process for the TO.

b. Complete set of pretest mapping data in Radiation Absorbed Dose in silicon (RAD(Si)) = (cGy(Si)) and absorbed dose in tissue (cGy(tissue)) ±10% for each test location.

This requirement is met by using existing facility data to estimate STT distances and then refining these STTs by taking pretest GTD environment exposures. For each of these characterization exposures a series of TLDs are placed on the centerline axis of the simulator and exposed. These dosimeter readings are then utilized to calculate each required STT distance for a given dose rate environment and the exposure time required to achieve a given GTD. This calculation process must be performed for each electronic item to be exposed. The basic dose rate equation is presented as EQ3 and should be verified against the pretest mapping data. EQ4 can be used to select the STT distance for a given dose rate. The GDR for the GTD test should be selected between 30 and 300 cGy(Si)/sec and result in an exposure time of approximately one minute. The physical dimensions of the system under test will determine what the highest dose rate used will be. The system test position is selected to minimize the gamma dose gradients, which are calculated using EQ4. Once the STT distance (which maximizes GDR and minimizes dose gradient) is determined the time of exposure is calculated using Equation 8.

$$t_{exposure} = \frac{\gamma_{req}}{\dot{\gamma}_{map}}$$

Equation 8. Time of Exposure.

where
$f_{req.}$ = GTD requirement
map = GDR at mapping point

c. Information required before a test can begin.

These include system familiarity and descriptions. Sizes and locations of mission critical electronic equipment and knowledge gained in the testing of other similar military equipment. Of primary importance, is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed, and insure that the GDR protection devices (if present) are included and evaluated. In addition, it is necessary to insure that: (1) every electronic assemblage will be properly exposed to the GTD environment while in a powered operational state, (2) the function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each exposure to the GTD environment, and (3) that each assemblage will have mounted to each surface dosimetry for recording the incident GTD environment. If GDR power down has been employed as a circuit protection method, then the GTD test should be

designed so that the percentage of gamma dose received after the circumvention time, is received with the system in a powered off nonoperational state.

The dosimetry at a minimum should be placed on all vertical surfaces (all surfaces if physically possible) of the LRU undertest, with the largest dimension of the TLD being perpendicular to the incident environment. These dosimeters are used to determine the incident environment on the surface of the LRU and can be used to estimate the internal gamma dose environment of an LRU.

d. Dosimetry from the gamma dose environment.

The TLDs should be placed as indicated in the section above and their location used to determine the gamma exposure for each specific LRU. The primary method of recording the gamma environment is through the use of TLDs which measure the total gamma energy received. The TLD measurement cGy(CaF_2(Mn)) is converted to Tissue and Silicon radiation absorbed dose by EQ. 6 and 7 with the GDR term replaced by the gamma dose term.

e. System orientation and data.

The system must be oriented such that all of the active electronic LRUs are exposed to the GTD environment while in a powered operational mode. The STT distance must be measured before each exposure to insure that the required levels are received as calculated above. Once all electronics have received the initial level, the system should be positioned to receive the 200% levels as indicated in para 4.2.1 above. Any LRU which will exceed the 200% level should be shielded from the environment using lead. Shielding may be required during various phases of the gamma dose test based on the physical geometry and spatial location of LRUs of the system under test. Again it is emphasized that the primary goal is to expose all the LRUs to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to different manufacturing processes, and to account for the small sample size evaluated (usually one). The operational data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each GTD exposure. Dosimetry from all LRUs which have a line of sight path to the gamma dose source should be removed (please note to leave those which are for measuring the test sequence total dose) and evaluated for dose achieved. Utilizing this real time exposure data, the STT distance should be refined using EQ 5 through 8 above until the desired environment has been realized.

4.2.3 Gamma Dose Analytical Procedures.

Section 4.2.2 provides the methods utilized to obtain data during a GTD environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements , the LRUs which were exposed, the orientation in which they were exposed, and the results of the post-test checkouts. If any gamma dose effects are noted then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The GTD test environment should be

scored against the criterion, differences greater than 20% should be addressed. These differences should include the reason for the difference and its effects on the system evaluation.

4.2.4 Gamma Dose Follow up.

Follow up to the initial gamma dose environment should be performed for each susceptible area. This follow up should include both a system or LRU level retest and an electronic microcircuit analysis. Additionally, the impact in annealing must be incorporated into the experimental design and assessed WRT the impact on the Mission Critical Functions of the evaluated test item(s).

4.3 Neutron Fluence Test Procedures.

4.3.1 General Neutron Fluence Procedures.

In this section, the general procedures for performing a NF test will be discussed. The first requirement is an in depth familiarity with the system and its normal operation. Without this baseline knowledge, an assessment can not be made. The second requirement is the realization that the NF environment will be simulated by some form of nuclear reactor. These reactors are all limited in both size and output and are incapable of producing an adiabatic environment over a large area. These reactors all produce a radiation field which is best modeled as a point source with a decrease in magnitude based on the inverse square law. Consequently the reactors are capable of producing the required environment only for narrow isocontours. It is therefore necessary to test a system in various orientations and configurations with respect to the incident radiation environment. These orientations must allow for the exposure of all electronic equipment to the required base test level and also insure that the neutron gradients are kept to a minimum. Since the primary damage mechanism for the neutron fluence environment is crystal lattice damage the system under test does not require power during the radiation exposure. Therefore that system should be disassembled to the smallest practical elements in order to reduce neutron exposure gradients and to eliminate the unnecessary neutron activation of non-essential material. By removing and exposing only the active electronic microcircuits the bulk of material making up a system (i.e. shelters, shielding, and enclosures) are not irradiated. Performing the test with the system disassembled reduces the activated volume and thereby reduces the radiation decay (cool down) time and personnel exposures. The system should also be exposed to increased levels in order to account for: the nonadiabatic environment, deviation in dosimetry, system variability, and to allow for a safety margin. It is recommended that 200% of the test level be used to increase the confidence provided by a small sample size (usually one).

4.3.2 Detailed Neutron Fluence Procedures.

Presented in TOP 1-2-612 section 5.5 is a set of data required while performing a NF test. Each of these required data will be discussed below:

a. Detailed description of the method of producing the NF test environment including photographs of the test facility setup showing test system location relative to the neutron radiation source.

This requirement is best attained by being familiar with available facilities. If not, then reviewing the facilities listed in the DTRA "A Complete Guide to Nuclear Weapons Effects Simulator Facilities and Applications", (2001 Edition) and requesting a facilities brochure which should contain a description of the radiation producing method (a Fast Burst Reactor (FBR) is the preferred source for NF irradiation) and specifications. With current technology, digital photographs are considered the best method of archiving a test setup / procedure. In addition to photographs, the archive and report generation should utilize one of the many computer graphics programs available that can generate clear and concise drawings of the physical test setup. However, with the advent of inexpensive digital cameras, photographs accounting all details of the test setup, performance checkouts and actual induced effects are critical to the documentation process for the TO.

b. Complete set of pretest mapping data expressed in 1 MeV equivalent (damage in silicon) neutron/cm^2. Because of the extreme control required in the operation of most reactors the facility will maintain a set of control parameters and dosimetry which can be used to accurately predict experimental exposures. Once a familiarity with the facility has been established there is usually little need for a neutron mapping exposure.

This requirement is obtained by taking several pretest NF environment exposures. For each of these characterization exposures a series of Sulfur activation dosimetry and TLDs are placed on the centerline axis of the proposed experiment position. These dosimeter readings are then utilized to calculated the required source to target distance for a given neutron environment (for a pulse operation) or the exposure time required to achieve a given neutron dose (for a power operation). The method (pulse or power) of receiving NF is not of importance as long as the received dose is converted to 1 MeV equivalent damage in silicon. The 1 MeV equivalent conversions is used as a normalization factor between the different types of reactors and operations. Reactors in general are of the water moderated style or the free air mass moderated style, with operations being either pulsed or continuous power. Again the best source found for determining experiment location for a given fluence is the reactor operations crew.

c. Information required before a test can begin.

These include system familiarity and descriptions. Sizes and locations of mission critical electronic equipment and knowledge gained in the testing of other similar military equipment. Of primary importance is the ability to utilize this data in developing a coherent test procedure. These procedures should include but are not limited to using the electrical schematics to determine possible susceptible areas, insure that all electronics are exposed. In addition, it is necessary to insure that: (1) the function of all mission essential equipment will be baselined before testing and that this baseline will be repeated after each exposure to the neutron environment, (2) each exposed assemblage will have mounted to each surface dosimetry for recording the incident neutron environment. This dosimetry should be placed on the exposed assemblages at a point on the side which corresponds to the midplane of the active electronic microcircuits (this assumes disassembly to the circuit card assembly level).

d. Dosimetry from the NF environment.

The sulfur pellets and TLDs should be placed as indicated in the section above and their location used to determine the overall neutron exposure for each specific LRU. The primary method of recording the neutron environment is through the use of sulfur pellets which measure the total neutron energy greater than 3 Mev received. The dosimetry must be changed after every exposure. The sulfur measurement (neutrons/cm^2 greater than 3 MeV) is converted to 1 Mev equivalent damage in silicon by a conversion factor (approximately 6.7 for an experiment at 26 inches for the White Sands Missile Range (WSMR) Fast Burst Reactor (FBR) and changes as a function of distance). This conversion factor is dependent on the neutron spectrum produced by the reactor and the distance at which the test is performed. Therefore the conversion to 1 MeV equivalent is not generic and must be obtained from the facility dosimetry specialist.

e. System orientation and data.

The system must be oriented such that all of the active electronics are exposed to the NF environment. This should be accomplished at the Circuit Card Assemblies (CCAs) level if possible, in order to reduce neutron dose gradients. The STT distance must be measured before each exposure to insure that the required levels are received. Once all electronics have received the initial level, the system should be positioned to receive the 200% levels as indicated in para. 6.1 above. Again it is emphasized that the primary goal is to expose all the LRUs to levels which will account for: all error terms in dosimetry and data recording, response differences in microcircuits due to manufacturing processes, and to account for the small sample size evaluated (usually one). The operational data taken on the system should be performed using system functional check sheets which include a description of the operation to be performed and the nominal results. A functional data sheet should be completed after each neutron exposure. Dosimetry from all LRUs which have been exposed to the NF environment should be removed and evaluated for the fluence achieved.

4.3.3 <u>Neutron Fluence Analytical Procedures</u>.

Section 4.3.2 provides the methods utilized to obtain data during a NF environment test. The data acquired should be processed and presented in tabular form wherever possible. These tables should include exposure number and measurements, the LRUs which were exposed, the CCAs which were exposed, the orientation in which they were exposed, and the results of the post exposure checkouts. If any NF effects are noted then particular attention must be provided in the report for these effects. This post-test analysis should include post-test failure analysis, identification of electronic microcircuits affected, impacts on mission critical functions, and possible corrective actions. The NF environment should be scored against the criterion, differences greater than 20% should be addressed. These differences should include the reason for the difference and its effect on the system evaluation.

4.3.4 <u>Neutron Fluence Follow up</u>.

Follow up to the initial NF environment should be performed for each susceptible area. This follow up should include both an LRU/CCA level retest and an electronic microcircuit analysis. A total system retest will not be required if the CCA functionality can be verified by an electronic

bench test. Additionally, the impact of temperature must be a consideration when assessing item items to the NF environment.

5. DATA REQUIRED.

5.1 Gamma Dose Rate.

a. Detailed description of the method and facility of producing the GDR test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

b. Complete set of pretest mapping data in radiation absorbed dose (cGy) in silicon (cGy(Si))(±10%) and cGy(tissue) (±10%) for each expected test location.

c. Risetime and pulse-width (FWHM) of each gamma pulse.

d. Results from the pretest analysis to include data from other GDR test/analysis programs performed on similar military systems.

e. Test data and/or analytical data and analysis on the Hardness Critical Items (HCIs) and the test system from contractor such as Design Parameter Reports (DPRs).

f. List of all active electronic piece-parts utilized in the test system.

g. Piece-part characterization and test data on HCIs from available databases.

h. Detailed description, serial numbers, and dimensions of each subsystem of the test system.

i. Results of applicable piece-part tests and circuit analysis to include DMs.

j. Description of statistical method(s) used to determine DMs.

k. Detailed description and electrical schematics of test circuits utilized.

l. Detailed description of all mission essential functions.

m. Duration of each gamma radiation pulse (nsec) (±10%).

n. Gamma total dose expressed in cGy(Si) and cGy(tissue) (±10%).
o. Detailed description of all utilized data acquisition procedures and hardware/software.

p. Detailed description of expected system configurations, orientations, and modes.

q. Detailed description and documentation of all inspections, downtime (sec) (±10%), operational checks, and maintenance procedures.

r. Type and location of dosimeters on the test system for each test exposure.

s. Conversion factors (±10%) used to convert cGy(CaF_2) to cGy(Si) and cGy(tissue).

t. Complete list of safety and environmental concerns.

u. TIRs.

v. Diagnostic data on all failure(s) or unacceptable degradation(s).

5.2 Gamma Total Dose.

a. Detailed description of the method and facility of producing the gamma total dose test environment including photographs of the test facility setup showing test system location relative to the gamma radiation source.

b. Complete set of pretest mapping data in radiation absorbed dose (cGy) in silicon (cGy(Si))(±10%) and cGy(tissue) (±10%) for each expected test location.

c. Results of the pretest analysis and data from other GTD test/analysis programs performed on similar military systems.

d. List of all active electronic piece-parts utilized in the test system.

e. Test data and/or analytical data and analysis on HCIs and the test system from contractor such as DPRs.

f. Piece-part characterization and test data on HCIs from available databases.

g. Detailed description, serial numbers, and dimensions of each subsystem of the test system.

h. Detailed description and electrical schematics of test circuits utilized.

j. Results of piece-part tests and circuit analysis to include DMs.

k. Description of statistical method(s) used to determine DMs.

l. Detailed description of all mission essential functions.

m. Duration of each gamma radiation pulse (sec) (±5%).

n. GTD expressed in cGy(Si) and cGy(tissue) (±10%).

o. Detailed description of all utilized data acquisition procedures.

p. Detailed description and documentation of all inspections, downtime (sec) (±10%), operational checks, and maintenance procedures.

q. Type and location of dosimeters on the test system for each test exposure.

r. Conversion factors (±10%) used to convert cGy(CaF_2) to cGy(Si) and cGy(tissue).

s. Complete list of safety and environmental concerns.

t. TIRs.

u. Diagnostic data on all failure(s) or unacceptable degradation(s).

5.3 Neutron Fluence.

a. Detailed description of the method and facility of producing the neutron fluence test environment including photographs of the test facility setup showing test system location relative to the neutron fluence source.

b. Time duration (sec) (±1 sec.) and nominal power level (watts) (±5%) for each steady-state operation.

c. Documentation of each radiation pulse signature to include the shape, width at FWHM (□sec) (±10), and burst size (Delta T ºC) (±10%).

d. Results of the pretest analysis and data from other neutron fluence test/analysis programs performed on similar military systems.

e. Test data and/or analytical data and analysis on HCIs and the test system from contractor such as DPRs.

f. List of all active electronic piece-parts utilized in the test system.

g. Piece-part characterization and test data on HCIs from available databases.

h. Detailed description (to include material composition, serial numbers, and dimensions of each test item of the test system.

i. Complete set of electrical schematics.

j. Results of applicable piece-part test and circuit analysis to include DMs.

k. Description of statistical method(s) used to determine DMs.

l. Detailed description of all mission essential functions.

n. Detailed description of utilized data acquisition procedures, hardware/software.

o. Detailed description of test item or system configurations, orientations, and modes.

p. Detailed description and documentation of all inspections, downtime (sec) (±10%), operational checks, and maintenance procedures.

q. Type and location of dosimeters on the test system for each test exposure.

r. Conversion factors (±10%) used to convert cGy(CaF2) to cGy(Si) and cGy(tissue).

s. Complete list of safety and environmental concerns.

t. TIRs.

u. Diagnostic data on all failure(s) or unacceptable degradation(s).

v. Results of all neutron environment measurements with neutron fluence expressed in terms of 1 Mev (Si) equivalent damage fluence (n/cm^2), (±10%) neutron dose expressed in cGy(Si) (±10%), and gamma dose expressed cGy(Si) and cGy(tissue) (±10%).

w. Complete list of possible expected radioactive isotopes and corresponding half-lifes.

6. PRESENTATION OF DATA.

6.1 Data Appropriation and Compliance.

Results from the pretest analysis, and all other applicable nuclear survivability programs will be analyzed and, whenever possible, incorporated into all facets of the NTSA on the test system. The incorporation of all available analytical and test data will be used to enhance and reduce the overall scope of the test program.

Data from free-field environment measurements will be utilized to define the test environment and quantify the differences between the test and criterion environments. Differences greater than fifteen percent between the primary parameter values will be analyzed to determine the effect on the test results. Procedures and analysis utilized will be clearly documented.

Results from the pretest analysis, system test and post-test determination/analysis, and environment compliance will be integrated into an analysis of the survivability of the test system's configuration to the test and then the United States Army Nuclear and Combating Weapons of Mass Destruction Agency (USANCA) environments. The final analysis of the test system may show different damage and mission impacts than the test system's results due to extrapolation and correction of environmental and test results to account for variances and differences.

The final survivability analysis of the baseline system configuration to the USANCA requirements will utilize, incorporate, and integrate data and results of the test system survivability determination and analysis of the configuration differences. This final survivability analysis of the baseline configuration may show results different than the test system analysis

due to extrapolations and/or corrections for configuration differences.

6.2 Data Reduction.

All raw data collected during nuclear survivability testing must be processed to remove data acquisition and dosimetry error and to refine simulation deficiencies. All analytical procedures and methods utilized to process these raw data must be documented along with example calculations in " Appendix B: Test Data" of a detailed test report. The entire collection of raw data should not be presented in the test report because of its excessive bulk. Reduced data that are pertinent to the analysis and support the determinations should be included in tabular form in the main body.

Quantitative and analytical techniques along with adequate response measurements must be utilized during all nuclear survivability testing. A simple GO / NO-GO test is not acceptable and will not enable the survivability of the system to be determined.

The data must demonstrate that the test hardware was adequately tested to its specified criteria in each nuclear test environment. The test environments will then be processed and combined with the pretest results, along with the body of data analyzed, so that the survivability of the test configuration can be determined. Analytical techniques such as Messenger-Spratt, and curve fitting must be discussed with constraints and inputs to enable the reader to determine adequacy. All analytical data reduction methods must be identified and presented in Appendix B of the test report.

Statistical analysis such as computing the mean, standard deviation, 99/90 tolerance limit, minimum data, DMs, and criteria compliance percentages should be performed on all nuclear survivability system test data. Type and quality of data will determine the statistical methods to be employed.

Whenever an electronic piece-part possesses sample size of eleven or more and the data can be assumed to come from a normally distributed population, a 99/90 tolerance limit will be calculated. This statistical figure, calculated from the mean, standard deviation and sample size, is the limit below (or above, depending on the specific parameters of interest) which we expect (with 90% confidence) 99% of the population to survive. In cases where the underlying distribution of the data is not known and cannot be assumed to be normal, nonparametric statistics should be used. In these cases, larger sample sizes will be required to provide the same confidence of attaining the DM. It should be noted that some adjustment to the desired confidence level and/or population proportion may be necessary for nonparametric techniques (e.g., the 90/90 nonparametric tolerance limit requires a sample size of 22, the 95/90 nonparametric tolerance limit requires a sample size of 45, and the 99/90 nonparametric tolerance limit requires a sample size of 230). Any changes in population proportions or confidence levels should be coordinated with the Army Evaluation Command (AEC) independent evaluator or Developmental Test Command (DTC) independent assessor.

In electronic piece-part testing, the minimum preferred sample size is eleven because one device is utilized as a control device, four unexposed devices are required for the GDR phase, four unexposed devices are required for the total gamma dose phase, and two unexposed devices are

required for the neutron fluence phase. If possible, two of the electronic devices should be tested to all required test environments.

In system level testing, the preferred sample size of seven is desired to provide an acceptable level of statistical confidence. However, this sample size is extremely difficult to obtain in system level testing. Therefore, stress testing is used to provide additional confidence in the results. Typical stress levels are 1X, 1.5X, 2X and 3X for INR.

6.3 Data Presentation.

Data must be presented in a clear and concise manner, so they are easy to understand and support the conclusions regarding the nuclear survivability of test item/system hardware as specified in Appendix G of TOP 1-2-612. To accomplish this, a combination of charts, graphs, drawings, tables, and photographs should be utilized.

a. Tables should be utilized to present the following data:

(1) Irradiation / Illumination Test Results Summary.

(2) Equipment Test Matrix.

(3) Criteria Compliance.

(4) Test Point Data.

(5) Statistical Analysis.

(6) Criteria and Test Standards.

(7) Test Comparisons.

b. Photographs should be utilized to present the following data:

(1) Dosimetry Locations.

(2) Test Configurations, Orientations, and Set-ups.

(3) Test Facility's Data Acquisition Set-up.

(4) Locations of Other Utilized Measuring Devices.

(5) Real Time Response.

(6) Test Facility Layout.

(7) Visible Damage.

c. Drawings should be utilized when photography is not available or inadequate to display critical data supporting the results and/or conclusions. Drawings may also be utilized to illustrate effects and test orientations / configurations.

d. Charts and Graphs should be utilized to present the following data:

(1) Test Schedules.

(2) Criteria Compliance.

(3) Previous Test Comparisons.

(4) Comparisons of Test Point Data with the Test Item in Different Configurations, Orientations, or Modes.

(5) Test Program Status.

e. Circuit analysis and DM determination for each high risk HCI must be provided in Appendix B. As a minimum, the data must include:

(1) Test Circuit Layout.

(2) Utilized Analytical Techniques.

(3) Application of Utilized Data.

(4) Design Margins.

APPENDIX A. ABBREVIATIONS.

ADC	- Analog to Digital Converter
AEC	- Army Evaluation Command
AR	- Army Regulation
ASTM	- American Society for Testing and Materials
CaF_2(Mn)	- Calcium Fluoride (Manganese)
CCA	- Circuit Card Assembly
cGy	- centi-Gray (equivalent to one RAD)
CPD	- Capabilities Performance Document
cm	- centi-meter
cm^2	- square centi-meter
CMOS	- Complementary Metal Oxide Semiconductor
Co_{60}	- Cobalt 60
DAC	- Digital to Analog Converter
DC	- Direct Current
DM	- Design Margin
DOD	- Department of Defense
DODI	- Department of Defense Instruction
DPR	- Design Parameters Report
DTC	- Developmental Test Command
DTRA	- Defense Threat Reduction Agency
EE PAL	- Electrically Erasable Programmable Array Logic
FBR	- Fast Burst Reactor

Fτ	- Gain Bandwidth Product
FWHM	- Full Width Half Maximum
GBP	- Gain Bandwidth Product
GDR	- Gamma Dose Rate
GTD	- Gamma Total Dose
HCI	- Hardness Critical Item
HOB	- Height of Burst
INR	- Initial Nuclear Radiation
JFET	- Junction Field Effect Transistor
keV	- Kilo-Electron Volts
km	- Kilo-meter
kT	- Kilo-Ton
LINAC	- Linear Accelerator
LRU	- Line Replaceable Unit
m	- meter
MeV	- Million Electron Volts
Mn	- Manganese
MNS	- Materiel Needs Statement
MOS	- Metal Oxide Semiconductor
MOSFET	- Metal Oxide Semiconductor Field Effect Transistor
NBS	- National Bureau of Standards
NF	- Neutron Fluence

NHC	- Nuclear Hardening Criteria
NIST	- National Institute of Standards and Technology
NMOS	- N-type Metal Oxide Semiconductor
nsec	- nano-seconds
NTSA	- Nuclear Test and Survivability Assessment
NWE	- Nuclear Weapons Effects
ORD	- Operational Requirements Document
PAL	- Programmable Array Logic
PGTD	- Prompt Gamma Total Dose
PROM	- Programmable Read Only Memory
RAD	- Radiation Absorbed Dose
Sec	- Second
Si	- Silicon
SCR	- Silicon Controlled Rectifier
SDRAM	- Synchronous Dynamic Random Access Memory
SOI	- Silicon on Insulator
SOS	- Silicon on Sapphire
STT	- Source To Target
SUT	- System Under Test
TLD	- Thermoluminescent Dosimeter
TO	- Test Officer
TOP	- Test Operation Procedures
TRIGA	- Training, Research, Isotopes, General Atomics

TTL	- Transistor Transistor Logic
µsec	- Micro-Second
USANCA	- United States Army Nuclear and Combating Weapons of Mass Destruction Agency
UV	- Ultra Violet
WSMR	- White Sands Missile Range

APPENDIX B. GLOSSARY.

1. Dose - A general term denoting the quantity of radiation or energy absorbed. In general dose is specified based on absorbing material.

2. Dosimeter - Instrument to detect and measure accumulated radiation exposure. A common dosimeter is a pencil-size ionization chamber with a self reading electrometer, which is used for personnel monitoring.

3. Gamma - Gamma radiation emitted at the time of fission of a nucleus.

4. Gamma Ray - Short-wavelength electromagnetic radiation (photon) of nuclear origin.

5. Ionization - The process by which a neutral atom or molecule acquires a positive or negative charge.

6. MeV - One million electron volts. An electron volt is the amount of energy acquired by an electron when it falls through a potential of 1 volt.

7. Neutron - A neutral molecular particle of approximately one atomic mass unit.

8. Neutron Fluence - Integral of all neutrons entering a specific fluence volume.

9. Nuclear Radiation - Particulate and electromagnetic radiation emitted from atomic nuclei during various nuclear processes.

10. X-rays - Penetrating electromagnetic radiations whose wavelengths are shorter than those of visible light. In nuclear reactions, it is customary to refer to photons originating in the nucleus as gamma rays and those originating in the extra-nuclear part of the atom as X-rays.

APPENDIX C. INR TESTING REQUIREMENTS.

Table C-1: INR Testing Requirements for Generic Part Families.

Generic Damage Levels:

GDR: Upset < 1E9 cGy(Si)/sec
Damage < 1E9 cGy(Si)/sec
Based Upon 20 nsec Pulse-width

GTD: < 1600 cGy(Si)

Neutron Fluence : < 1E12 n/cm2

Generic Part Family	Gamma Dose Rate Testing	Gamma Total Dose Testing	Neutron Fluence Testing	Comments
1. Diodes	No	No	No	
2. PIN Diodes	Yes	No	No	
3. Temperature Compensated Diodes	No	No	Yes	
4. Zener Diodes	No	No	No	** Special Circuit Situations
5. High Fτ (> 50 MHz) Transistors	No	No	No	** Special Circuit Situations
6. Low Fτ (< 50 MHz) Transistors	No	No	Yes	
7. Power Transistors	No	No	Yes	
8. Crystals	No	Yes	Yes	
9. Crystals Oscillators	**Yes	Yes	Yes	**Technology Dependent
10. Operational Amplifiers	No	No	Yes	
11. Comparators	Yes	No	Yes	
12. CMOS* Analog Switches	Yes	**Yes	Yes	**Certain Manufacturers
13. Fixed Regulators	No	No	Yes	

Complimentary Metal Oxide Semiconductor (CMOS)

Table C-1: INR Testing Requirements for Generic Part Families (Cont).

Generic Part Family	Gamma Dose Rate Testing	Gamma Total Dose Testing	Neutron Fluence Testing	Comments
14. DC to DC Converters	**Yes	**Yes	**Yes	**Technology Dependent
15. ADC	**Yes	**Yes	**Yes	**Technology Dependent
16. DAC	**Yes	**Yes	**Yes	**Technology Dependent
17. JFETs	Yes	No	Yes	
18. MOSFETs	Yes	Yes	Yes	
19. Discrete Timers	No	No	No	
20. Linear Timers	No	No	Yes	
21. SCRs	Yes	No	Yes	
22. Unijunction Transistors	No	No	Yes	
23. Discrete Opto-Electronics	No	No	Yes	
24. Opto-Couplers	No	No	Yes	
25. EE PAL	**Yes	**Yes	No	** Technology Dependent
26. TTL PAL	No	No	No	
27. UV PAL	No	Yes	No	
28. EE PROM	**Yes	**Yes	No	** Technology Dependent
29. UV PROM	**Yes	No	No	** Technology Dependent
30. TTL PROM	No	No	No	
31. NMOS PROM	No	Yes	No	
32. Static RAMs	Yes	Yes	No	
33. IDT RAMs	Yes	Yes	No	

APPENDIX D. GAMMA DOSE RATE PIECE-PART THRESHOLDS.

Table D-1: Gamma Dose Rate (GDR) Concern Thresholds.

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Analog Switches	CMOS	1E7 – 1E8	1E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability / Must limit power to device safe region
Analog Switches	MOS/JFET	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Charge Coupled Devices (CCDs)	CCD	5E6 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Comparators	Bipolar / Linear	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability. Change of state
Comparators	CMOS	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability/ Change of state
Crystal Oscillators	Hybrid	1E7 – 1E9	1E9 – Above	Slight effects on frequency / Low Risk @ tactical GDR levels – Concern with control circuitry
Crystals	Linear	1E7 – 1E9	1E9 – Above	Slight effects on frequency / Low Risk @ tactical GDR levels
Darlingtons	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Potential concern @ tactical GDR levels / photocurrent generation will occur. Configuration dependent / Must limit power to device safe region
DC/DC Converter with Magnetic Feedback	Hybrid	1E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
DC/DC Converters with Optical Feedback	Hybrid	5E6 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability

Table D-1: Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Digital Devices	CML* ()	1E8 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur
Digital Devices	ECL**	5E8 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur. Change of state
Digital Devices	Gallium Arsenide	1E8 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur. Change of state
Digital Devices	I2L	1E8 – 5E9	5E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur. Change of state
Digital Devices	TTL	1E7 – 1E9	1E9 – Above	Low Risk concern @ tactical GDR levels / photocurrent generation will occur / Change of state
Digital Potentiometers	CMOS	5E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability / Data loss
Diodes – High Frequency	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Light Emitting (LEDs)	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Light Emitting (LEDs)	Gallium Arsenide Variants	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Photo	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Rectifier	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Reference / Zener / Suppression	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur
Diodes – Signal	Bipolar / Linear	1E6 - Above	N/A	Not concern @ tactical GDR levels / photocurrent generation will occur

* Current Mode Logic (CML)
* Emitter Coupled Logic (ECL)

Table D-1: Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Fully Programmable Gate Array (FPGA)	CMOS	1E7 – 5E8	1E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability. Loss of data
Insulated Gate Bipolar Transistors (IGBTs)	IGBT	1E7 – 1E9	1E9 – Above	Significant photocurrent generation will occur / Circuit Application is critical to acceptability. Configuration dependent
Logic Devices	TTL	1E7 – 1E9	1E9 – Above	Low Risk concern @ tactical GDR levels / photocurrent generation will occur / Change of state
Memory - DRAM	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability Change of state
Memory – EEPROM & Flash	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability Change of state
Memory – EEPROM & Flash	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability Change of state
Memory - FIFO	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Memory - PROM	TTL	1E7 – 1E9	1E9 – Above	Low Risk concern @ tactical GDR levels / photocurrent generation will occur / Change of state
Memory - ROM	TTL	1E7 – 1E9	1E9 – Above	Low Risk concern @ tactical GDR levels / photocurrent generation will occur / Change of state

Table D-1: Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Memory – SDRAM	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Memory – SRAM	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability / Data loss
Micro-Controllers	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Micro-Processors	Bipolar	1E7 – 1E9	1E9 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Micro-Processors	CMOS	5E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
MOSFETs – N-Channel	NMOS	1E7 – 1E9	1E9 – Above	Significant photocurrent generation will occur / Greatest concern – Push / Pull Configuration Burnout
MOSFETs – P-Channel	PMOS*	1E7 – 1E9	1E9 – Above	Significant photocurrent generation will occur / Greatest concern – Push / Pull Configuration Burnout
Multiplexers	CMOS	1E7 – 1E8	1E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability / Must limit power to device safe region
Multiplexers	MOS/JFET	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability

*PMOS – P-Channel Metal Oxide Semiconductor

Table D-1: Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Operational Amplifiers	BICMOS	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Operational Amplifiers	BIMOS	1E8 – 1E9	1E9 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Operational Amplifiers	Bipolar / Linear	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Operational Amplifiers	CMOS	1E7 – 5E8	5E8 – Above	Extremely sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Opto-Couplers – Photo-Diodes	Bipolar / Linear	1E6 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur
Opto-Couplers – Photo-Transistor / Diode	Bipolar / Linear	1E6 – 1E10	> 1E10	Not concern @ tactical GDR levels / photocurrent generation will occur
Opto-Electronics --Solid State Relays	Hybrid	1E6 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Passive Devices	Many	N/A	> 1E13	Not concern @ tactical GDR levels / Applicable to secondary effects, corrective actions and circuit acceptability
Programmable Logic Device – EEPROM	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state
Programmable Logic Device – SRAM	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up, memory corruption and burnout / current limiting and power removal critical to survivability / circuit acceptability / Change of state

Table D-1: Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Silicon Controlled Rectifiers SCRs/ Thyristor	Bipolar / Linear	N/A	1E6 – 1E9	Significant photocurrent generation will occur due to Four Layer Path / Will turn On due to photocurrent generation / primary Nuclear Event Detection Device
Timers	Bipolar / Linear	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Timers	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Transistors GBWP < 50 MHz	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Transistors GBWP > 50 MHz	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Transistors - Junction Field Effect (JFET)	FET	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Transistors – Photo	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Uni-Junction Transistors (UJTs)	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Not concern @ tactical GDR levels / photocurrent generation will occur / Configuration dependent
Voltage References	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Voltage References	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability

Table D-1: Gamma Dose Rate (GDR) Concern Thresholds (Continued).

Piece-Part Type	Technology	GDR Upset Threshold (cGy(Si)/sec)	GDR Latch-up / Burnout Threshold (cGy(Si)/sec)	Comments
Voltage Regulators – Linear – Fixed and Adjustable	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Voltage Regulators – Linear – Fixed and Adjustable	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Voltage Regulators – Switching	Bipolar / Linear	1E7 – 1E9	1E9 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability
Voltage Regulators – Switching	CMOS	1E7 – 5E8	5E8 – Above	Sensitive to latch-up and burnout / current limiting and power removal critical to survivability / circuit acceptability

APPENDIX E. GAMMA TOTAL DOSE PIECE-PART THRESHOLDS.

Table E-1: Gamma Total Dose (GTD) Concern Thresholds.

Piece-Part Type	Technology	GTD Threshold Range (cGy(Si)	Comments
Analog Switches	CMOS	1K – Above	Increased Rds(ON) and leakage currents
Analog Switches	MOS/JFET	2K – Above	Increased Rds(ON) and leakage currents
Charge Coupled Devices (CCDs)	CCD	10K - Above	Not concern @ tactical GTD levels
Comparators	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Comparators	CMOS	3K - Above	Increase in Vos
Crystal Oscillators	Hybrid	5K - Above	Slight effects on frequency / Low Risk @ tactical GTD levels – Concern with control circuitry
Crystals	Linear	10K - Above	Slight effects on frequency / Low Risk @ tactical GTD levels
Darlingtons	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
DC/DC Converter with Magnetic Feedback	Hybrid	10K - Above	Not concern @ tactical GTD levels
DC/DC Converters with Optical Feedback	Hybrid	3K - Above	The optical feedback design is the most sensitive to the GTD
Digital Devices	CML	10K - Above	Not concern @ tactical GTD levels
Digital Devices	ECL	10K - Above	Not concern @ tactical GTD levels
Digital Devices	Gallium Arsenide	> 20K	Not concern @ tactical GTD levels
Digital Devices	I2L	10K - Above	Not concern @ tactical GTD levels
Digital Devices	TTL	10K - Above	Not concern @ tactical GTD levels
Digital Potentiometers	CMOS	1.5K - Above	The primary concern is the EEPROM input becoming all "1s" / Data corruption and shift in Logic Thresholds
Diodes – High Frequency	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Diodes – Light Emitting (LEDs)	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Diodes – Light Emitting (LEDs)	Gallium Arsenide Variants	> 20K	Not concern @ tactical GTD levels
Diodes – Photo	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Diodes – Rectifier	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels

Table E-1: Gamma Total Dose (GTD) Concern Thresholds (Continued).

Piece-Part Type	Technology	GTD Threshold Range (cGy(Si))	Comments
Diodes – Reference / Zener / Suppression	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Diodes – Signal	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Fully Programmable Gate Array (FPGA)	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
Insulated Gate Bipolar Transistors (IGBTs)	IGBT	2K - Above	Increase in VCE(Sat)
Logic Devices	TTL	10K - Above	Not concern @ tactical GTD levels
Memory - DRAM	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
Memory – EEPROM & Flash	CMOS	1.5K - Above	The primary concern is the EEPROM input becoming all "1s" / Data corruption and shift in Logic Thresholds / Data Loss can occur @ 8K Rads(Si)
Memory - EPROM	CMOS	1.5K - Above	The primary concern is the EEPROM input becoming all "1s" / Data corruption and shift in Logic Thresholds / Data Loss can occur @ 8K Rads(Si)
Memory - FIFO	CMOS	5K – Above	Data corruption and shift in Logic Thresholds
Memory - PROM	TTL	10K - Above	Not concern @ tactical GTD levels
Memory - ROM	TTL	10K - Above	Not concern @ tactical GTD levels
Memory – SDRAM	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
Memory – SRAM	CMOS	2K – Above	Data corruption and shift in Logic Thresholds
Micro-Controllers	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
Micro-Processors	Bipolar	10K - Above	Not concern @ tactical GTD levels
Micro-Processors	CMOS	3K – Above	Data corruption and shift in Logic Thresholds
MOSFETs – N-Channel	NMOS	1.5K - Above	Decrease in Vgs(th) and increase in Rds(ON)
MOSFETs – P-Channel	PMOS	1.5K - Above	Increase in Vgs(th) and increase in Rds(ON)
Multiplexers	CMOS	1K – Above	Increased Rds(ON) and leakage currents
Multiplexers	MOS/JFET	2K – Above	Increased Rds(ON) and leakage currents

Table E-1: Gamma Total Dose (GTD) Concern Thresholds (Continued).

Piece-Part Type	Technology	GTD Threshold Range (cGy(Si)	Comments
Operational Amplifiers	BICMOS	3K – Above	Increase in Vos and decrease in Large Signal Voltage Gain
Operational Amplifiers	BIMOS	3K – Above	Increase in Vos and decrease in Large Signal Voltage Gain
Operational Amplifiers	Bipolar / Linear	> 20K	Not concern @ tactical GTD levels
Operational Amplifiers	CMOS	3K – Above	Increase in Vos and decrease in Large Signal Voltage Gain
Opto-Couplers – Photo-Diodes	Bipolar / Linear	5K – Above	Decrease in transmissivity of material between diodes
Opto-Couplers – Photo-Transistor / Diode	Bipolar / Linear	5K – Above	Decrease in transmissivity of material between diodes / transistor pair
Opto-Electronics --Solid State Relays	Hybrid	2K – Above	Device will not Turn ON, due to threshold shifts
Passive Devices	Many	> 20K	Not concern @ tactical GTD levels / Applicable to secondary effects, corrective actions and circuit acceptability
Programmable Logic Device – EEPROM	CMOS	1.5K - Above	The primary concern is the EEPROM input becoming all "1s" / Data corruption and shift in Logic Thresholds
Programmable Logic Device – SRAM	CMOS	2K – Above	Data corruption and shift in Logic Thresholds
Silicon Controlled Rectifiers (SCRs) / Thyristors	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Timers	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Timers	CMOS	2K – Above	Changes in Logic Thresholds

Table E-1: Gamma Total Dose (GTD) Concern Thresholds (Continued).

Piece-Part Type	Technology	GTD Threshold Range (cGy(Si)	Comments
Transistors GBWP < 50 MHz	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Transistors GBWP > 50 MHz	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Transistors - Junction Field Effect (JFET)	FET	> 20K	Not concern @ tactical GTD levels
Transistors – Photo	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Uni-Junction Transistors (UJTs)	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Voltage References	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Voltage References	CMOS	2K - Above	The primary concern is charge pumps internal to the reference
Voltage Regulators – Linear – Fixed and Adjustable	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Voltage Regulators – Linear – Fixed and Adjustable	CMOS	3K - Above	
Voltage Regulators – Switching	Bipolar / Linear	10K - Above	Not concern @ tactical GTD levels
Voltage Regulators – Switching	BiMOS / BiCMOS/ CMOS	2K - Above	

APPENDIX F. NEUTRON FLUENCE PIECE-PART THRESHOLDS.

Table F-1: Neutron Fluence (NF) Concern Thresholds.

Piece-Part Type	Technology	NF Threshold Range (n/cm^2)	Comments
Analog Switches	CMOS	> 3E12	
Analog Switches	MOS/JFET	> 3E12	
Charge Coupled Devices (CCDs)	CCD	2E12 - Above	Increase in dark current and Decrease in Charge Transfer Efficiency (CTE)
Comparators	Bipolar / Linear	1E12 - Above	Increase in Bias Currents, Vos and Decrease in Open Loop Gain and Sink Current
Comparators	CMOS	> 5E12	
Crystal Oscillators	Hybrid	> 5E12	Slight effects on frequency / Low Risk @ tactical NF levels – Concern with control circuitry
Crystals	Linear	> 5E12	Slight effects on frequency / Low Risk @ tactical NF levels
Darlingtons	Bipolar / Linear	1E12 - Above	Messenger-Spratt cannot account for actual Darlington NF degradation
DC/DC Converter with Magnetic Feedback	Hybrid	2E12 - Above	Slight Increases / Decreases in Output Voltage
DC/DC Converters with Optical Feedback	Hybrid	5E11 - Above	The optical feedback design is the most sensitive to the NF / Output Voltage goes to Zero or Input Voltage
Digital Devices	CML	> 1E13	Not concern @ tactical NF levels
Digital Devices	ECL	> 1E13	Not concern @ tactical NF levels
Digital Devices	Gallium Arsenide	> 1E13	Not concern @ tactical NF levels
Digital Devices	I2L	> 1E13	Not concern @ tactical NF levels
Digital Devices	TTL	> 1E13	Not concern @ tactical NF levels
Digital Potentiometers	CMOS	1E12 - Above	Device will not re-program due to charge pump failure
Diodes – High Frequency	Bipolar / Linear	> 1E13	Not concern @ tactical NF levels
Diodes – Light Emitting (LEDs)	Bipolar / Linear	5E11 - Above	Substantial Decrease in Light Output / Generally not an issue due to diagnostic circuit application
Diodes – Light Emitting (LEDs)	Gallium Arsenide Variants	8E11 - Above	Substantial Decrease in Light Output
Diodes – Photo	Bipolar / Linear	3E11 - Above	Substantial Decrease in Light Detection/ Increases in Dark Current / Circuit application is critical

Table F-1. Neutron Fluence (NF) Concern Thresholds (Continued).

Piece-Part Type	Technology	NF Threshold Range (n/cm^2)	Comments
Diodes – Rectifier	Bipolar / Linear	> 1E13	Not concern @ tactical NF levels
Diodes – Reference / Zener / Suppression	Bipolar / Linear	1E12 - Above	Decrease in Output Voltage
Diodes – Signal	Bipolar / Linear	> 1E13	Not concern @ tactical NF levels
Fully Programmable Gate Array (FPGA)	CMOS	> 1E13	Not concern @ tactical NF levels
Insulated Gate Bipolar Transistors (IGBTs)	IGBT	8E11 - Above	Increase in VCE(Sat)
Logic Devices	TTL	> 1E13	Not concern @ tactical NF levels
Memory - DRAM	CMOS	> 1E13	Not concern @ tactical NF levels
Memory – EEPROM & Flash	CMOS	1E12 - Above	Device will not re-program due to charge pump failure
Memory – EPROM	CMOS	> 5E12	Not concern @ tactical NF levels
Memory - FIFO	CMOS	> 1E13	Not concern @ tactical NF levels
Memory - PROM	TTL	> 1E13	Not concern @ tactical NF levels
Memory - ROM	TTL	> 1E13	Not concern @ tactical NF levels
Memory – SDRAM	CMOS	2E11 – Above	Data Corruption through insufficient refresh rate / Missing Bits
Memory – SRAM	CMOS	> 1E13	Not concern @ tactical NF levels
Micro-Controllers	CMOS	> 1E13	Not concern @ tactical NF levels
Micro-Processors	Bipolar	> 1E13	Not concern @ tactical NF levels
Micro-Processors	CMOS	> 1E13	Not concern @ tactical NF levels
MOSFETs – N-Channel	NMOS	> 1E13	Not concern @ tactical NF levels
MOSFETs – P-Channel	PMOS	> 1E13	Not concern @ tactical NF levels
Multiplexers	CMOS	> 3E12	
Multiplexers	MOS/JFET	> 3E12	

Table F-1. Neutron Fluence (NF) Concern Thresholds (Continued).

Piece-Part Type	Technology	NF Threshold Range (n/cm^2)	Comments
Operational Amplifiers	BICMOS	1E12 - Above	Increase in Bias Currents, Vos and Decrease in Open Loop Gain
Operational Amplifiers	BIMOS	1E12 - Above	Increase in Bias Currents, Vos and Decrease in Open Loop Gain
Operational Amplifiers	Bipolar / Linear	1E12 - Above	Increase in Bias Currents, Vos and Decrease in Open Loop Gain
Operational Amplifiers	CMOS	> 5E12	
Opto-Couplers – Photo-Diodes	Bipolar / Linear	1E12 - Above	Substantial Decrease in Current Transfer Ratio
Opto-Couplers – Photo-Transistor / Diode	Bipolar / Linear	5E11 – Above	Substantial Decrease in Current Transfer Ratio
Opto-Electronics - -Solid State Relays	Hybrid	5E11 – Above	Device will not Turn ON, due to insufficient drive
Passive Devices	Many	> 1E14	Not concern @ tactical NF levels / Applicable to secondary effects, corrective actions and circuit acceptability
Programmable Logic Device – EEPROM	CMOS	1E12 – Above	Device will not re-program due to charge pump failure
Programmable Logic Device – SRAM	CMOS	> 1E13	Not concern @ tactical NF levels
Silicon Controlled Rectifiers (SCRs) / Thyristors	Bipolar / Linear	5E11 – Above	Substantial Increase in Holding Current requirement
Timers	Bipolar / Linear	1E12 – Above	Increase in Reset Time / Circuit application is critical
Timers	CMOS	> 1E13	Not concern @ tactical NF levels
Transistors GBWP < 50 MHz	Bipolar / Linear	5E11 - Above	Substantial Decrease in Gain
Transistors GBWP > 50 MHz	Bipolar / Linear	3E12 - Above	Substantial Decrease in Gain

Table F-1. Neutron Fluence (NF) Concern Thresholds (Continued).

Piece-Part Type	Technology	NF Threshold Range (n/cm^2)	Comments
Transistors - Junction Field Effect (JFET)	FET	> 1E13	Not concern @ tactical NF levels
Transistors – Photo	Bipolar / Linear	3E11 - Above	Extremely sensitive to NF degradation
Uni-Junction Transistors (UJTs)	Bipolar / Linear	5E11 - Above	Substantially Increases RB1 and RB2
Voltage References	Bipolar / Linear	7E11 - Above	Significant shift in Output Voltage (Increase or Decrease) / Substantial Increase in Line & Load Regulation
Voltage References	CMOS	> 5E12	
Voltage Regulators – Linear – Fixed and Adjustable	Bipolar / Linear	7E11 - Above	Significant shift in Output Voltage (Increase or Decrease) / Substantial Increase in Line & Load Regulation
Voltage Regulators – Linear – Fixed and Adjustable	CMOS	> 5E12	
Voltage Regulators – Switching	Bipolar / Linear	7E11 - Above	Significant shift in Output Voltage (Increase or Decrease) / Substantial Increase in Line & Load Regulation
Voltage Regulators – Switching	BiMOS / BiCMOS	7E11 - Above	Significant shift in Output Voltage (Increase or Decrease) / Substantial Increase in Line & Load Regulation
Voltage Regulators – Switching	CMOS	> 3E12	

APPENDIX G. REFERENCES.

1. Army Regulation (AR) 70-75, 2 June 2006, subject: Survivability of Army Personnel and Materiel.

2. Department of Defense Instruction 5000.2, 12 May 2003, subject: Operation of the Defense Acquisition System.

3. Army Nuclear Hardening Criterion for System Under Test (SUT).

4. American Society for Testing and Materials.

5. Test Operations Procedure 1-2-612, May 2008, subject: Nuclear Environment Survivability.

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a. DASIACSR-94-009, Guide to Nuclear Weapons Effects Simulation Facilities and Techniques, 2001.

b. G.C. Messenger and M.S. Ash, The Effects of Radiation on Electronic Systems, published by Van Mostrand Reinhold, 1986.

c. S. Glasstone and P.J. Dolan, The Effects of Nuclear Weapons, published by United States Department of Defense and United States Department of Energy, 1977.

d. Illinois Institute Of Technology Research Institute, Nuclear Weapon Effects Class Notes, 1991.

e. TEDT-SV, White Sands Nuclear Effects Facility Technical Capabilities, Survivability, Vulnerability and Assessment Directorate, 2008.

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